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Impact of Nanoparticles on Performance of Heat Transfer of Crude-Oil Based Cu, Al_2O_3, and SWCNTs

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Abstract

This paper focuses on the impact of nanoparticles on heat transfer performance. More specifically, in the presence of crude oil-based Cu, Al_2O_3, and SWCNTs. However, the impact of the thermal radiation and the volume fraction on the velocity $f(\eta)$ and temperature $\theta(\eta)$ distribution are presented and discussed. The similarity transformation is applied to convert the PDEs to ODEs. Thought-out the simulation, the Runge-Kutta Fehlberg algorithm of order four/five and shooting method is employed to analyze the numerical solutions using Maple 18 software. Results obtained indicated that all the temperature of the crude-oil based SWCNTs, Cu and Al_2O_3, have improved. However, the temperature of the Cu-crude-oil happens to be more energetic than that of SWCNTs and Al_2O_3. This is because the thermal and electrical conductivity of Cu is stronger and more durable when compared with other conductive materials.

Keywords: *Nanoparticles; Heat transfer; Differential equations; Crude oil.*

1. Introduction

Heat transfer is an area of thermal engineering involving the conversion, use, exchange, and generation of heat energy amongst physical systems. Heat transfer can also be described as the thermal energy in transit as a result of a spatial temperature difference, and it is classified into various mechanisms, including the transfer of energy by phase changes, thermal radiation, thermal convection (TCV), and thermal conduction (TCD) [1-2]. These mechanisms usually occur simultaneously in the same system despite the fact that their characteristics differ. Thermal convection occurs when the heat is transferred along the flow of matter using the bulk fluid motion, including liquid or gas, and causing the heated fluid to flow away from the source. Thermal convention above any hot surface arises when hot air expands, thereby becoming less dense and rises. Contrarily, thermal conduction is an uninterrupted microscopic conversation of energy (kinetic) of the particle due to boundaries between two systems. The transfer of heat by thermal conductions is often through a solid. Suppose the temperature of an object differs from that of its surroundings. These objects would be regulated in order to be at the same temperature through the flow of heat. At this point, both the body and its surroundings are said to be thermal equilibrium. The thermal radiation (TR) heat transfer occurs through any transparent medium, including gas, solid, or fluid, or through a vacuum, which is due to electromagnetic wave propagation. For instance, the transfer of heat from the sun. In contrast, TR is known for electromagnetics wave, thermal convection, and thermal conduction involving particle. Energy is distributed from TCV by microscopic or bulk fluid motion as a result of certain molecular diffusion. This implies that the level at which heat is passing across a special material (thermal conductivity) of ethylene glycol, water, or oil, has an essential role to play in the transfer of heat, as applied in numerous applications of engineering and industrial to reduce operating temperature [1].

However, as a result of poor traditional means employed in transferring heat fluid involving thermal conductivity, the enhancement in cooling ability is limited [2]. In addition to this, the recent bulk fluid transfer of heat such as oil and gas involving the use of solid particles (nano-sized, 1-100nm) has an additive suspend in the based fluid. The studied scheme is a modified procedure for improving the transfer of heat via addition and experimental test of the conductive solids into fluids. The main idea behind using nanometer-sized particles is to disperse the solid particles in fluid in order to enhance thermal conductivity.

Nanofluid is a liquid containing a dispersion of submicronic solid particles (nanometer-sized particles), known as nanoparticles. Stephen Choi (1995) was among the early researchers to introduce the term of nanofluids [3]. The main objective of using the nanometer-sized particles is diffusing particles (solid) in the fluid, thereby boosting conductivity. With regards to real-life application, nanometer-sized particles have been shown to be a booster of the transfer of heat by an average of 50% despite the volume ratio of the nanoparticle base being >0.3% [4]. More so, the nanoparticles have an advantage in thermal conductivity boosting compared to other nanometer-sized particles with different based fluid, the nanometer-sized particles [1, 5-7].

Regardless of the efficiency of the nanoparticles, numerous researchers continue to study the nanoparticles with the aim of improving the thermal conductivity properties via the addition and experimental test of various conductive solids into the fluids. With this, it is believed the nanoparticles would act similar to fluid while the thermal conductivity behaves like a metal. Some of the known nanoparticles employed are often made of copper (Cu), alumina Al_2O_3, and Single-Walled Carbon Nanotubes (SWCNTs), just to mention a few.

Motivated by the recent trend in this area and for the reason of the current additive working fluid, it would be interesting to explore the influence of heat transfer characteristics and behavior, including viscosity, transfer of heat, thermal conductivity, and many more.

In this study area, physicists and mathematicians are amongst the several scholars that contributed to the field of thermal conductivity. With numerous studies showing that nanometer-sized particles provide a higher boosting advantage of heat transfer with regards to the based fluid yet, the real number of available experimental data with regard to nanofluid thermal particles are still few, especially in an oil base [8].

On the other way, it has been exhibited that, for a disposed of concentration, nanoparticle shape enacts an extensive role both in thermal conductivity and viscosity adaptation [9]. Timofeeva *et al.* [9] regulated an investigational analysis on the impact of nanoparticle shape on alumina nanofluids viscosity and thermal conductivity. Various nanoparticle shapes (platelets, blades, spherical, bricks, and cylindrical) were utilized over the experimentation [10]. Murshed *et al.* [11] studied the first investigational analysis on thermal conduction improvement due to the shape of nanoparticles included in the suspension and further reported an experimental analysis utilizing cylinder-like (rod) shapes nanoparticles. Singh *et al.* [12] investigated the behavior of nanoparticles of silicon carbide (SiC), acknowledging a shape-affirm platelet or disc and constantly diffused in the water on thermal conductivity and enrichment of mechanical assets. Zhou *et al.* [13] reported a theoretical analysis to evaluate non-spherical nanoparticles in nanofluid's thermal conductivity, utilizing a differential forceful medium theory. A few shapes of nanometer-sized particles analyzed are shuttle-like shape [14] and cylindrical rods [10].

In this research direction, our major focus is to study the impact of nanoparticles on the performance of the transfer of heat. More specifically, the effect of thermal radiation and volume fraction in the presence of crude oil-based Cu, Al_2O_3 and SWCNTs.

2. Model formulation

A two-dimension with sturdy MHD boundary layer flow along with heat transfer of crude oil-based is considered in this paper. This includes the crude oil-based nanofluid that past an overextended surface assimilated in the presence of nanoparticles materials and radiation of thermal energy. It is supposed that there is no slippage exists between the crude oil-based copper (Cu), alumina Al_2O_3, and SWCNTs, and all are in thermal equilibrium. The x and y co-ordinate are considered and measured along with the plate. The free stream velocities and stretching are $U_w(x) = bx$ and $U_w(x) = ax$, respectively. $T_w(x) = T_\infty + cx^n f$ is presented as the plate temperature. The flow structure and systems coordinate of the proposed model follows from [15].

Therefore, the governing equation is given in equation (1) - (3) below;

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$\left(-U_\infty \frac{\partial U_\infty}{\partial x} + u\frac{\partial y}{\partial x} + v\frac{\partial u}{\partial x}\right) = \frac{\mu_{nf}}{\rho_{nf}}\frac{\partial^2 u}{\partial y^2} - \frac{\sigma_{nf}B_0^2}{\rho_{nf}}(u - U_\infty) \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k_{nf}}{(\rho C_p)_{nf}}\frac{\partial^2 T}{\partial y^2} - \frac{1}{(\rho C_p)_{nf}}\frac{\partial q_r}{\partial y} \tag{3}$$

However, the boundary conditions are given in equation (4) below

$$y = 0, av = 0, T = T_w(x), u = U_w(x), y \to \infty: T = T_\infty, u = U_\infty(x) \tag{4}$$

Using stream function definition, we have that

$u = \frac{\partial \psi}{\partial y}$ and $v = -\frac{\partial \psi}{\partial y}$, where the transformation variables are given as

$$\psi = (x,y) = \sqrt{av_{nf}}\,xf(\eta), \eta = y\sqrt{\frac{a}{v_{nf}}}, \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty} \tag{5}$$

The ratio of the velocity and the Prandtl number of crude-oil is presented as $\lambda = \frac{b}{a}$ and $Pr = \frac{v_f}{\alpha_f}$, respectively. Also, the radiation and the magnetic parameters are given as $R = \frac{4\sigma_e T_c^3}{\beta_R k_f}$ and $M = \frac{\sigma_{nf}B_0^2}{\rho_{nf}}$, respectively.

After some algebraic works, we solved simultaneously, using 2-dimensional boundary layer for the three fundamental fluid dynamics equations. Alongside the x and y axis, we considered u and v respectively as the velocity components, while p and ρ are the pressure and density, respectively. The system of the equation is partial differential equations (PDEs), which are converted into the ODEs using similarity transformation. On top of that, the PDEs governing equation is converted into the following form of ODEs. The converted ODEs from PDEs are given in equation (6).

$$f^{II} = (f^I)^2 - \lambda^2 - M\left(\frac{\sigma_{nf}}{\sigma_f}\right)\left(\frac{\rho_f}{\rho_{nf}}\right)(\lambda - f^I) - ff^{II} \tag{6}$$

$$\theta^{II} = \frac{\left(1-\xi+\frac{(\rho C_p)_{nf_s}}{(\rho C_p)_f}\right)\left(\frac{\mu_{nf}}{\mu_f}\right)}{\left(\frac{\rho_f}{\rho_{nf}}\right)\left(\frac{k_{nf}}{k_f}\right)}\left(\frac{Pr}{1+\frac{4}{3}\frac{R}{\left(\frac{k_{nf}}{k_f}\right)}}\right)(f\theta^I - nf^I\theta) \tag{7}$$

along with the boundary conditions

$$f(0) = 0, f^I(0) = 1, \theta(0) = 1; f^I(\infty) = \lambda, \theta^I(\infty) = 0 \tag{8}$$

In this paper, the following friction and nanofluid physical properties in [15] are considered and defined;

Nux friction -	$Nux = \left(\frac{k_{nf}}{k_f}\right)\left(1 + \frac{4}{3}\frac{R}{\left(\frac{k_{nf}}{k_f}\right)}\right)\theta^I(0)$
Skin friction -	$C_f = \left(\frac{\mu_{nf}}{\mu_f}\right)f^I(0)$
Thermal-diffusivity -	$\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_f}$
Density -	$\rho_{nf} = (1-\zeta)\rho_f + \zeta\rho_s$

Nanofluid-Dynamic viscosity - $\mu_{nf} = \frac{\mu_f}{(1-\zeta)^{2.5}}$

Nanofluid heat - $\frac{\sigma_{nf}}{\sigma_f} = 1 + \frac{3\left(\frac{\sigma_f}{\sigma_f}-1\right)\zeta}{\left(\frac{\sigma_f}{\sigma_f}+2\right)-\left(\frac{\sigma_f}{\sigma_f}-1\right)\zeta}$

$$(\rho C_p)_{nf} = (1-\zeta)(\rho C_p)_f + \zeta(\rho C_p)_s, \frac{k_{nf}}{k_f} = \left[\frac{(k_s+(m-1)k_f)-(m-1)\zeta(k_f-k_s)}{(k_s+(m-1)k_f)+\zeta(k_f-k_s)}\right]$$

where the fraction of the volume of nanofluid and the dynamic viscosity of the based fluid are represented as ζ and μ_f , respectively.

The crude oil and the nanoparticle volumetric extension coefficient are β_s and β_s. ρ_s and ρ_f are the nanoparticle density and that of the base fluid. Both fluid and solid fraction thermal conductivity are represented as k_f and s, respectively. We follow [16] to convert the radiative heat flux as $q_{rad}^{II} = -\frac{4\sigma_e}{3\beta_R}\frac{\partial T^4}{\partial y}$, where β_R and σ_e are the coefficient of the absorption and Stefan-Boltzman constant. However, [15] explained that the frontier temperature is a function (exponential) alongside x and the flow has a variance of temperature, in which the function T^4 is termed as the continuous temperature. This is considered by developing T^4 in a Taylor's series around T_c. Higher order term is ignored and approximately arrived at $T^4 \simeq 4T_c^3 - 3T_c^4$.

We consider that

$$u = hf'p, \quad (9)$$

$$\frac{\partial u}{\partial x} = -\frac{3}{4}\alpha\frac{Rax^{\frac{1}{2}}}{x}\eta f'' - \frac{1}{2}\alpha\frac{Rax^{1/2}}{x^2}f', \quad (10)$$

$$v = \frac{Rax^{\frac{1}{4}}}{x}\alpha\left[\frac{3\eta}{4}f' - \frac{1}{4}f\right]. \quad (11)$$

It then follows that

$$\frac{\partial u}{\partial y} = hp^2 f'', \quad (12) \qquad \text{and } \frac{\partial^2 u}{\partial y^2} = hp^3 f''' \quad (13)$$

3. Results and discussion

In this part, we applied the shooting method for the solution of equations (6) – (7) with boundary conditions shown in (8). The shooting method had been studied by several scholars [17-18].

In [15], the authors used water as the base fluid, where here we extended the work in [15] to crude oil, which is used as the base fluid. Thus, the present article is compared with the radiation temperature profile. Our compared radiation velocity profile is displayed in Figure 1. The result is found to be excellent.

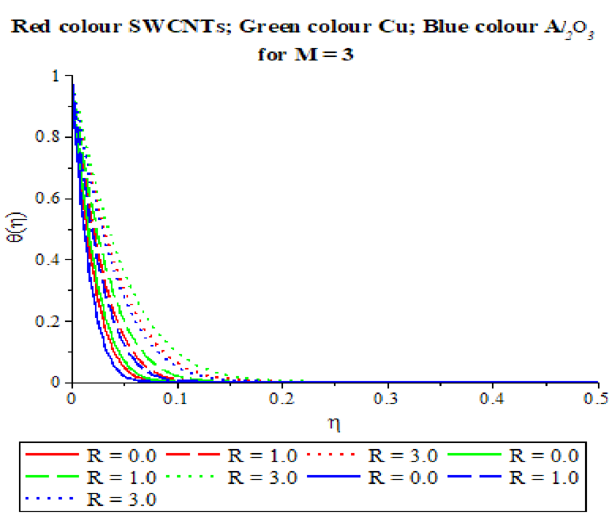

Figure 1. Showing the radiative temperature, $\theta(\eta)$, profile with Fig.5 in [15]

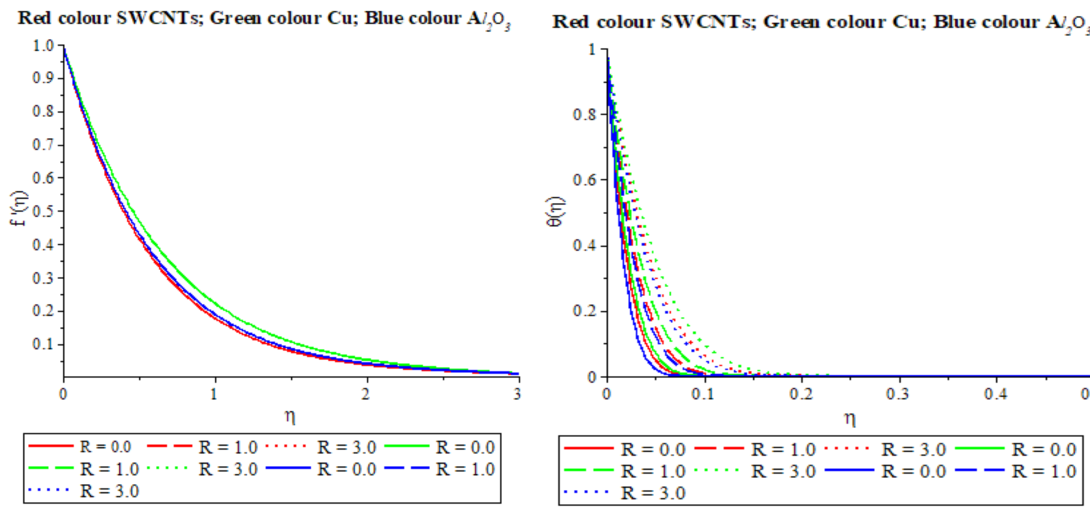

Figure 2. Thermal radiation parameter, R, for velocity, $f(\eta)$, and temperature, $\theta(\eta)$, circulation of the nanofluids

Figure 2, discussion of thermal radiation parameter, R,

1. It is indicated that the Cu velocity, $f(\eta)$, increase at a faster rate as compared with the SWCNTs and Al_2O_3–crude oil in the presence of the parameter of thermal radiation.
2. The Cu – crude oil of the velocity is dominant over its counterparts nanofluids.
3. The temperature, $(\theta(\eta)$, circulation for all nanofluids increase as a result of the increase in the thermal radiation parameter.
4. Particularly, the boundary depth of the surface of thermal of Cu – crude oil is dominant compare to that of its counterpart's nanofluids. This is a result that shows that the copper Cu thermal conductivity is stronger and more durable compare to other nanofluids.

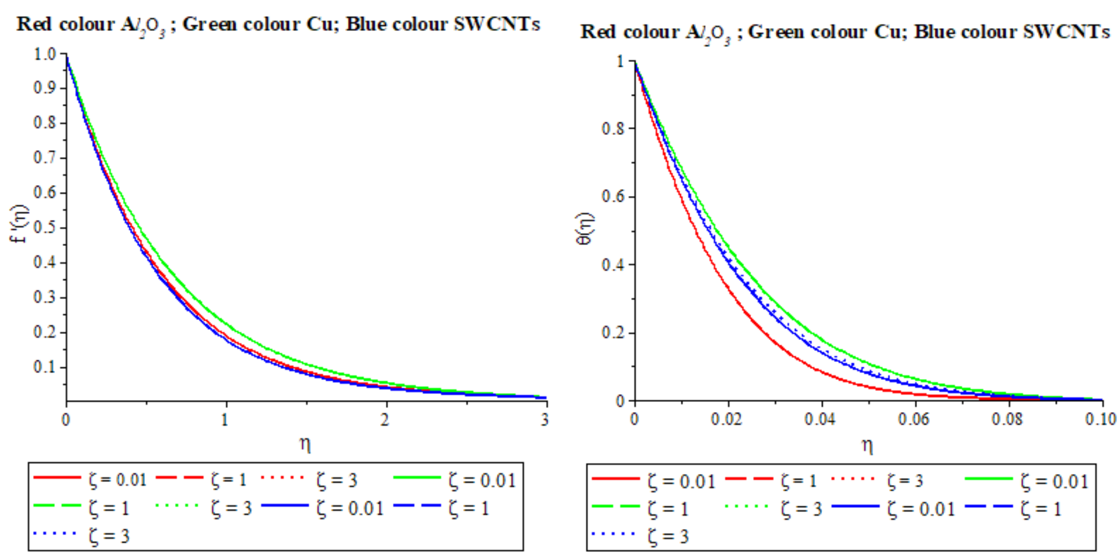

Figure 3. Volume fraction parameter, ζ, for velocity, $f(\eta)$, and temperature, $\theta(\eta)$, circulation of the nanofluids

Figure 3, discussion of nanoparticle volume fraction parameter, ζ

1. For the velocity, the Cu-crude-oil happens to be higher than that of other nanofluids
2. Similarly, the temperature, $(\theta(\eta)$, circulation for all Cu-crude-Oil increases.
3. It indicates that the MHD boundary layer Cu-crude-Oil heat transfer rate is monotonically sturdier compared to Al_2O_3 and SWCNTs that is based on water in the flow.

Table 1. Rate of heat temperature $\theta(\eta)$, dissimilar values of the nanoparticle thermal radiation transfer

R	SWCNTs	Cu	Al_2O_3
0.0	-53.07960164989275	-49.63609828915615	-58.12078411663454
1.0	-44.31061768625445	-40.34099656922497	-45.76072570299451
3.0	-36.41225419531059	-32.97125264458645	-37.34202234372449

It is indicated in Table 1 that all the temperature of the crude-oil based SWCNTs, Cu and Al_2O_3, improved, but that temperature of the Cu -crude-oil happens to be more energetic than that of others. This is as a result that the electrical and thermal conductivity of Cu are sturdier than other conductive materials.

Table 2. Rate of heat temperature, $\theta(\eta)$, dissimilar values of the nanoparticle volume fraction transfer

ζ	SWCNTs	Cu	Al_2O_3
0.01	-46.35644406794334	-42.515209083185425	-53.4446517467925
1.00	-46.35644406794334	-42.515209083185425	-53.4446517467925
3.00	-45.15481083013816	-42.515209083185425	-53.4446517467925

Table 2 shows that the MHD boundary layer Cu-crude-Oil heat transfer rate is monotonically sturdier than Al_2O_3 and water-based SWCNTs in the regime flow as volume, ζ, upsurges due to electrical and thermal conduction of Cu which are better than other conductive materials. Table 3 displays the properties of the thermo-physical of nanoparticle and crude oil.

Table 3. Thermo-physical properties of the water, crude oil, and nanoparticle

Fluid	$\rho(kg/m^3)$	$c_p(J/kgK)$	$k(W/mK)$	$\sigma(\Omega^{-1}m^{-1})$	Prandtl No.
Water	997.1	4179	0.613	5.5	6.82
Crude oil	870	1988	120	0.9	1490.51
Copper (Cu)	8933	385	401	50.6	-
Alumina Al_2O_3	3970	765	40	16.7	-
SWCNTs	2600	42.5	6600	1.26	-

4. Conclusion

This paper gives a report on the impact of various nanoparticles on the performance of the transfer of heat. The thermal radiation influence and the volume fraction on the temperature θ(η) and velocity f(η) distribution was presented and discussed. The similarity transformation was applied to obtain the ODEs from the defined PDEs. Thought-out the simulation, both methods of shooting and Runge-Kutta-method are used to acquire numerical solutions of the report. We considered several parameters variables as manipulated and constant variable to obtain lots of reactions and results, as reported below;

1. It is indicated that the Cu velocity f(η) increase at a faster rate as compared with the SWCNTs and Al_2O_3 crude oil in the presence of the parameter of thermal radiation.
2. The Cu– crude oil of the velocity is dominant than other nanofluids.
3. The temperature ($\theta(\eta)$, circulation for all nanofluids increase as a result of the increase in the parameter of thermal radiation.
4. In the case of thermal radiation on temperature ($\theta(\eta)$ circulation, the rate of heat transfers for Cu– crude oil reports a crucial role when viewed with its other counterparts with other nanofluids in the circulating system.

The MHD boundary layer Cu-crude-oil heat transfer rate is monotonically sturdier than SWCNTs (water-based) and Al_2O_3 in regime flow as volume, ζ, upsurges due to the electrical and thermal conduction of Cu, which is more durable than other conductive materials.

Nomenclature

B_0	*Flux density for the magnetic* $kgs^{-2}A^{-1}$,
a	*Stretching plate index -* s^{-1}
b	*Velocity index -* s^{-1},
c_p	*Specific heat at constant pressure -* $Jkg^{-1}K^{-1}$
k_f	*Thermal conduction of the base fluid* $kgms^{-3}K^{-1}$,
k_s	*Thermal conduction of base nanoparticle* $kgms^{-3}K^{-1}$
k_{nf}	*Thermal conduction of base nanofluid* $kgms^{-3}K^{-1}$
M	*Magnetic parameter,* $\frac{\sigma_{nf}B_0^2}{\rho_{nf}}(\frac{a^{-1}m^1(kgs^2A^1)-^2m^2}{kgm^{-1}s^1})$
	Wall nanoparticle K *volume fraction*
C_∞	*Volume fraction further from the wall nano-particle* K,
$C_{\infty,0}$	*Volume fraction due to stratification of the nanoparticle* K,
c_p	*Specific heat at constant pressure* $Jkg^{-1}K^{-1}$,
D_B	*Specific diffusivity* m^2s^{-1},
D_T	*Thermophoresis diffusion coefficient,* m^2s^{-1},
K	*Permeability of the porous medium* m^2,
Le	*Lewis number,* $\frac{v}{D_B}(\frac{m^2s^{-1}}{m^2s^{-1}})$
Nb	*Brownian motion parameter* $\frac{(pc)_\rho D_B(C_\infty - C_{\infty,0})}{(pc)_f\alpha}(\frac{Jm^{-3}k^{-1}m^2s^{-1}}{kgm^{-3}k^{-1}kk})$
Nr	*Buoyancy ratio,* $\frac{(p_\rho - P_{f\infty})(C_\infty - C_{\infty,0})}{P_{f\infty}\beta(T_\infty - T_{\infty,0})(1 - C_{\infty,0})}(\frac{kgm^{-3}k}{kgm^{-3}k^{-1}kk})$
Nt	*Thermophoresis parameter,* $\frac{(pc)_\rho D_T(T_\infty - T_{\infty,0})}{(pc)_f\alpha T_{\infty,0}}(\frac{Jm^{-3}k^{-1}m^2s^{-1}k}{Jm^{-3}k^{-1}m^2s^{-1}k})$
Pr	*Prandtl number* $\frac{v}{\alpha} = (\frac{m^2s^{-1}}{m^2s^{-1}})$
T	*Temperature of the fluid* K,
$x; y$	*Stream wise and cross-stream coordinates* m,
K^{-1}	*Base fluid density* kgm^{-3},
ρ	*Heat capacitance of nanofluid* Jkm^2K^{-1},
ρc_p	*Electrical conductivity* $\Omega^{-1}m^{-1}$,
σ	*Dynamic viscosity of base fluid* $kgm1m^{-1}s^{-1}$,
μ	*Thermal stratification parameter,* $\frac{4Ax}{T_\infty - T_{\infty,0}} = \frac{4A}{m}\left(\frac{s^{-1}}{s^{-1}}\right)$
η	*Similarity variable*
v	*Dynamic viscosity,* m^2s^{-1}
λ	*Porous parameter,* $\frac{v_fL}{ku_w}(\frac{m^2s^{-1}m}{m\,m^2s^{-1}})$
Ω	*Resistance* $kgm2s^{-3}A^{-2}$,
Ψ	*Dimensionless stream function*
f	*Dimensionless stream function*
θ, φ	*Dimensionless stream function*
γ	*Volume fraction*
$u; v$	*Components of velocity in x and y direction* ms^{-1},
T_w	*Wall* K *temperature*
T_∞	*Temperature of fluid further from the wall* K,
$T_{\infty,0}$	*Temperature of fluid due to stratification* K,
V_0	*Velocity of suction/injection* ms^{-1},

Greek symbols and subscripts

ζ	*Volume fraction of the nanoparticle* K,
β	*Thermal expansion coefficient*

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